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LIQUID CRYSTAL MATRIX IMAGE SOURCE FOR HELMET MOUNTED DISPLAYS (HMDs)

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The Liquid Crystal Matrix Image Source for Helmet Mounted Displays program was started in September 1982, with the dual objectives of, first, demonstrating the status of miniature liquid crystal light modulating devices and, second, developing a very high brightness image source for experimentation with helmet mounted display optical concepts. This image source was desired for experiments with helmet mounted display configurations in which an off-helmet image source is coupled to the on-helmet optical system through a coherent fiber optic bundle.

The approach taken was to project a high brightness image from a miniature reflective liquid crystal display device which was being developed under Tri-Service sponsorship and refined under company sponsorship. Substantial problems were encountered during the

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development of the liquid crystal devices, including excessive element and line defects, nonuniform contrast ratio, low contrast ratio, and short life. These problems were only partly resolved when the hardware was delivered on this program.

The hardware delivered on this program is comprised of an Illuminator Unit containing a high intensity arc lamp light source, an Arc Lamp Power Supply unit, and two identical Display Units. Except for the previously described problems with the development of the liquid crystal devices, the rest of the hardware generally meets the contract objectives.

The results of this program demonstrate that a liquid crystal approach can provide an extremely high brightness (>40,000 fL) replacement for the 1-inch CRTs commonly used in Helmet Mounted Displays.

PREFACE

The completion of the Liquid Crystal Matrix Image Source for Helmet Mounted Displays program was the result of a team effort by individuals from two areas of Hughes Aircraft Company. The Display Systems Laboratory, Radar Systems Group, provided overall program management, project and system engineering, and staff for electronic and mechanical design tasks. The projection optics were designed in the Optical Design Department of the Missile Systems Group. The Liquid Crystal Products area of the Industrial Electronics Group was responsible for the fabrication of the liquid crystal display module.

The team of individuals whose efforts contributed to this program included: Richard Bernstein, John Gunther, Ronald Hegg, Richard Murray, and Steven Shields. The program was monitored and directed for the Navy by Harold Green and James Brindle.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION AND SUMMARY

This document is the final technical report for the Liquid Crystal Matrix Image Source for Helmet Mounted Displays program, contract N62269-82-C-0702. The Liquid Crystal Matrix Image Source for Helmet Mounted Displays (LXHMD) program was started in September 1982, with the dual objectives of, first, demonstrating the status of miniature liquid crystal light modulating devices and, second, developing a very high brightness image source for experimentation with helmet mounted display optical concepts. This image source was desired for experiments with helmet mounted display configurations in which an off-helmet images source is coupled to the on-helmet optical system through a coherent fiber optic bundle. The light losses in the fiber optic bundle dictate high source brightness.

The miniature reflective liquid crystal devices used on this program were originally developed on the Miniature Flat Panel Display contract, DAAK70-78-C-0187. After completion of that program, the development of the liquid crystal devices was continued under company sponsorship. The LXHMD program was structured to take advantage of the company-sponsored effort without directly contributing to the liquid crystal technology development. The proposed program plan assumed that the major liquid crystal device development effort would be completed by the Summer of 1983, and that liquid crystal devices for use on this program could be constructed without risk or additional development at that time.

Substantial problems were encountered during the development of the liquid crystal devices, including excessive element and line defects, nonuniform contrast ratio, low contrast ratio, and short life. These problems lead to delays in the company-sponsored liquid crystal module development effort, and, in turn, to delays in the performance of the LXHMD program.

The development of reflective liquid crystal display modules was discontinued at the end of 1986. Additional devices were made for delivery on this program. While these devices represent the state-of-the-art at the time the development was discontinued, they fall short of the contract objectives in contrast ratio and number of defects.

The hardware delivered on this program, as shown in Figure 1, is comprised of an Illuminator Unit containing a high intensity arc lamp light source, an Arc Lamp Power Supply unit, and two identical Display Units. Except for the previously described problems with the development of the liquid crystal devices, the rest of the hardware generally meets the contract objectives.

While this program did not result in the development of a useful image source for experimentation with helmet mounted display systems, the results do show that a projected liquid crystal device can provide an image source with over 40,000 foot-Lambert brightness. Thus we believe that there is a very real potential for a liquid crystal image source form helmet mounted displays. The development of a very promising alternative liquid crystal technology, using transparent liquid crystal device containing thin-film transistors, is being continued at Hughes.

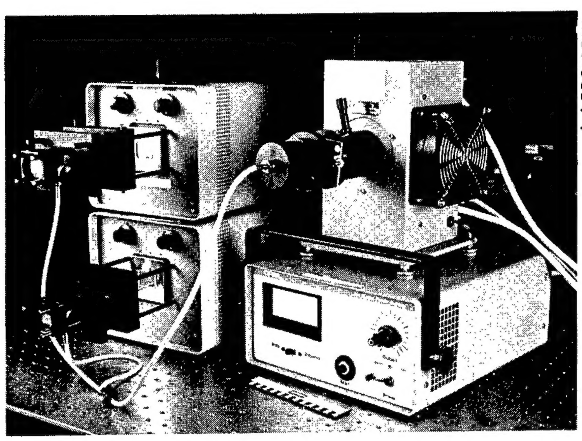

Figure 1. LXHMD Hardware. The Illuminator Unit is at the right on top of the Arc Lamp Power Supply. The two Display Units are at the left.

The design of the LXHMD hardware is discussed in the next section of this report. The third two sections sections describe the installation and operation of the hardware. The characteristics and performance of the hardware are summarized in the final section.

2. HARDWARE DESCRIPTION

SYSTEM DESIGN

The purpose of the Liquid Crystal Matrix Image Source for Helmet Mounted Displays (LXHMD) Program was to both demonstrate the status of miniature liquid crystal light modulating devices, and to provide a very high brightness image source for experimentation with helmet mounted display optical concepts. Thus the system was designed for operation in a laboratory environment only, and makes use of commercially available equipment where ever possible.

Block Diagram

As shown in Figure 2, System Block Diagram, the LXHMD hardware consists of the following units:

a. An Illuminator Unit containing a high intensity mercury-vapor arc lamp and the optical elements necessary to channel the light from the lamp into a fiber optic bundle for transmission to the display units;

b. An Arc Lamp Power Supply Unit which provides power to the Illuminator Unit;

c. Two identical Display Units that spatially modulate the light received from the Illuminator Unit (via a fiber optic light cable) to generate a very high brightness television image.

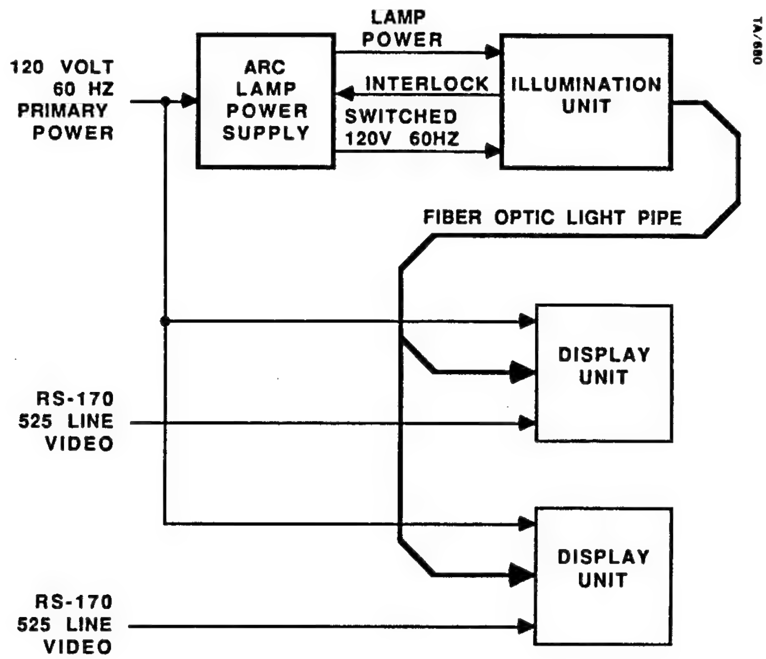

Figure 2. System block diagram.

Interfaces

The electrical interfaces to the LXHMD system are as follows:

Video. Each Display Unit accepts a standard EIA RS 170 525-line composite video input. The composite video information is displayed by ignoring the interlace and superimposing the two video fields such that the complete video image is presented on the 240 x 320-element liquid crystal device.

Power. The Display Units and the Arc Lamp Power Supply Unit operate from standard 100-120 volt, 60 hertz, single phase, primary power. The power consumption of these units are 30 watts for each Display Unit and 350 watts for the Arc Lamp Power Supply Unit including the blower. The Illuminator Unit includes a blower that also operates from 110-120 volt,

60 hertz, power. The power for this blower is normally received from an accessory socket on the back of the Arc Lamp Power Supply.

DISPLAY UNIT

As shown in the block diagram in Figure 3, the major components of the Display Unit are the liquid crystal device (LCD), the interface circuitry required to convert a standard 525-line video input into the signals required to create an image on the LCD, projection optics that form a minified high brightness image of the LCD surface, and three commercial power supply modules.

Liquid Crystal Device

The key component of each Display Unit is a miniature matrix liquid crystal display module shown in Figure 4. At the center of this device is the actual liquid crystal matrix with 240 rows of 320 picture elements. This device is constructed by sandwiching a layer of liquid crystal material between a transparent glass cover an a large silicon integrated circuit containing an X-Y

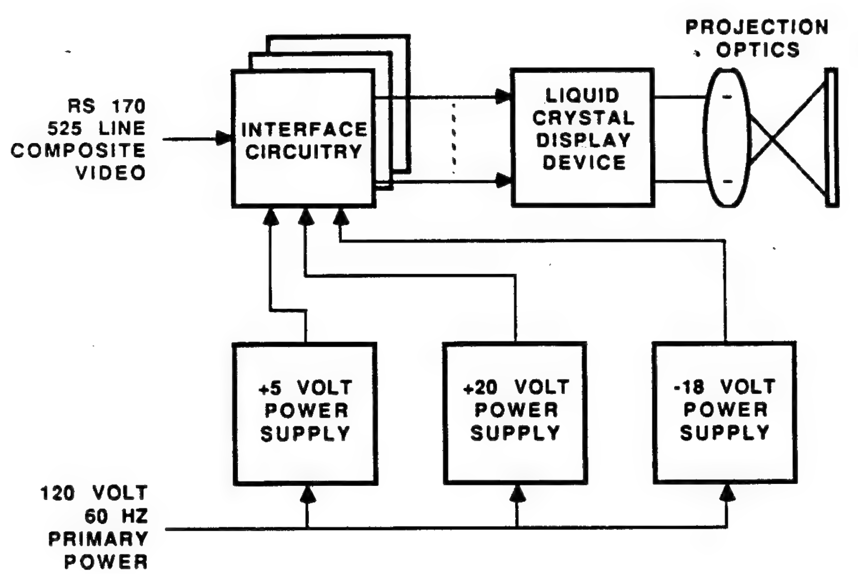

Figure 3. Display Unit block diagram.

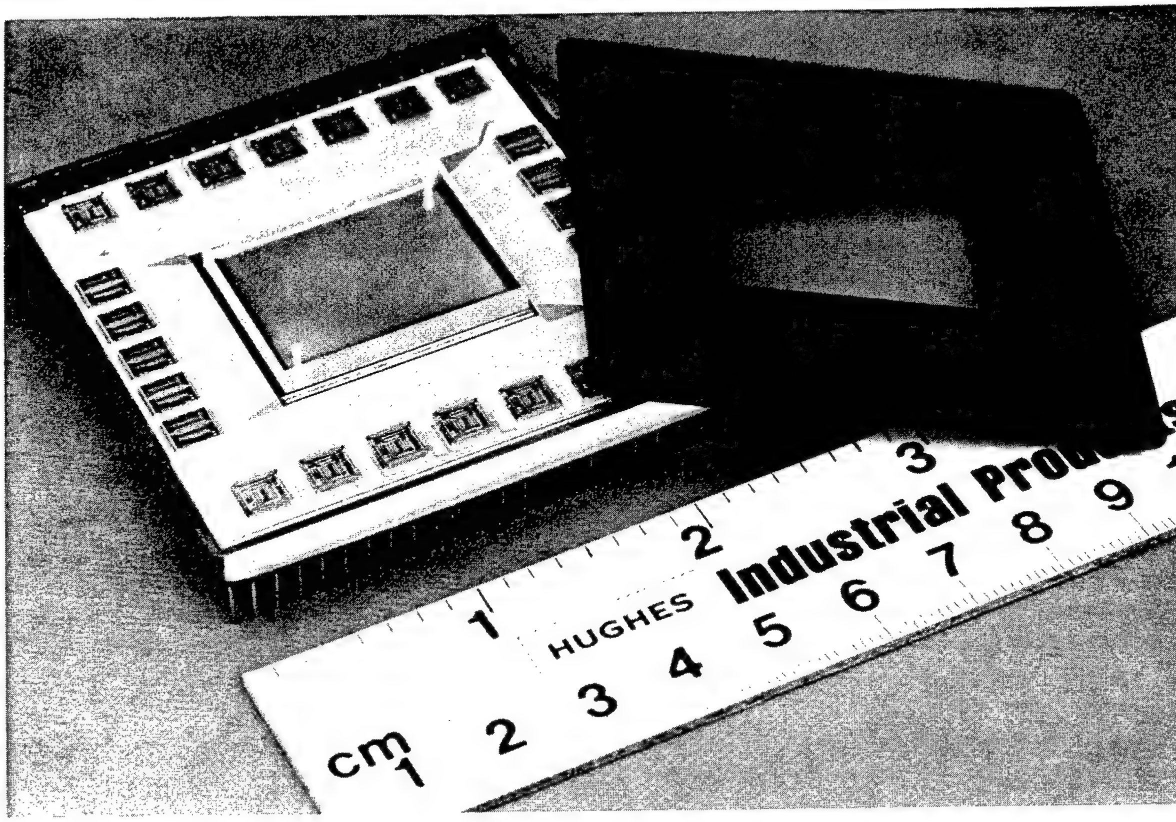

Figure 4. Miniature liquid crystal display device.

matrix of elemental electrodes. Beneath each elemental electrode is a single MOS transistor, a storage capacitor, and row and column addressing electrodes.

The liquid crystal display module also contains 24 LSI driver circuits, located around the perimeter of the display matrix. These drive circuits provide signals to the rows and columns of the display matrix.

The operation of the liquid crystal device is illustrated in Figure 5. The end of a fiber optic light pipe serves as a point source. Light emitted from the fiber is is collimated by the projection lens and directed towards the liquid crystal device. The light reflected from the liquid crystal device passes back through the projection lens. The light reflected by unenergized display pixels passes through a small aperture stop and continues on to form

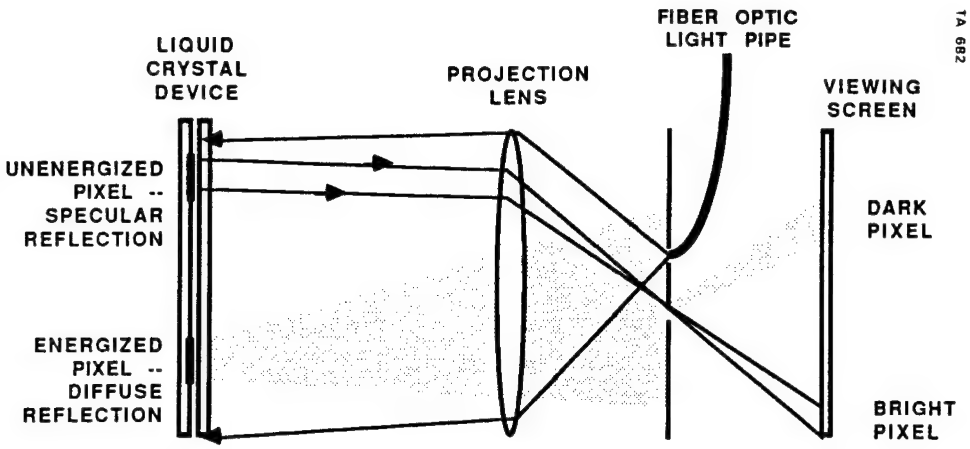

Figure 5. Principle of operation of scattering liquid crystal device.

bright spots in the projected image. The application of a voltage to energized display pixels causes the liquid crystal material to become turbid. These pixels diffusely reflect the incident light. The diffuse reflections do not focus on the aperture stop. Most of the light reflected from energized pixels is blocked, resulting in dark spots in the projected image. Thus the gray level of each projected pixel can be varied from white to black through the application of the corresponding voltage to each pixel in the liquid crystal matrix.

Interface Circuitry

As shown in Figure 6, the interface circuitry consists of three wire-wrap circuit modules. The circuitry on the Phase-Locked-Loop detects the horizontal and vertical synchronization pulses within the composite video. A delayed version of horizontal sync is used to accomplish DC restoration by clamping the video to ground during the blanking interval (back porch) following each horizontal sync pulse. A conventional phase-locked-loop, comprised of a phase detector, filter, voltage controlled oscillator, and a feedback counter on the Driver module is used to generate a stable element clock.

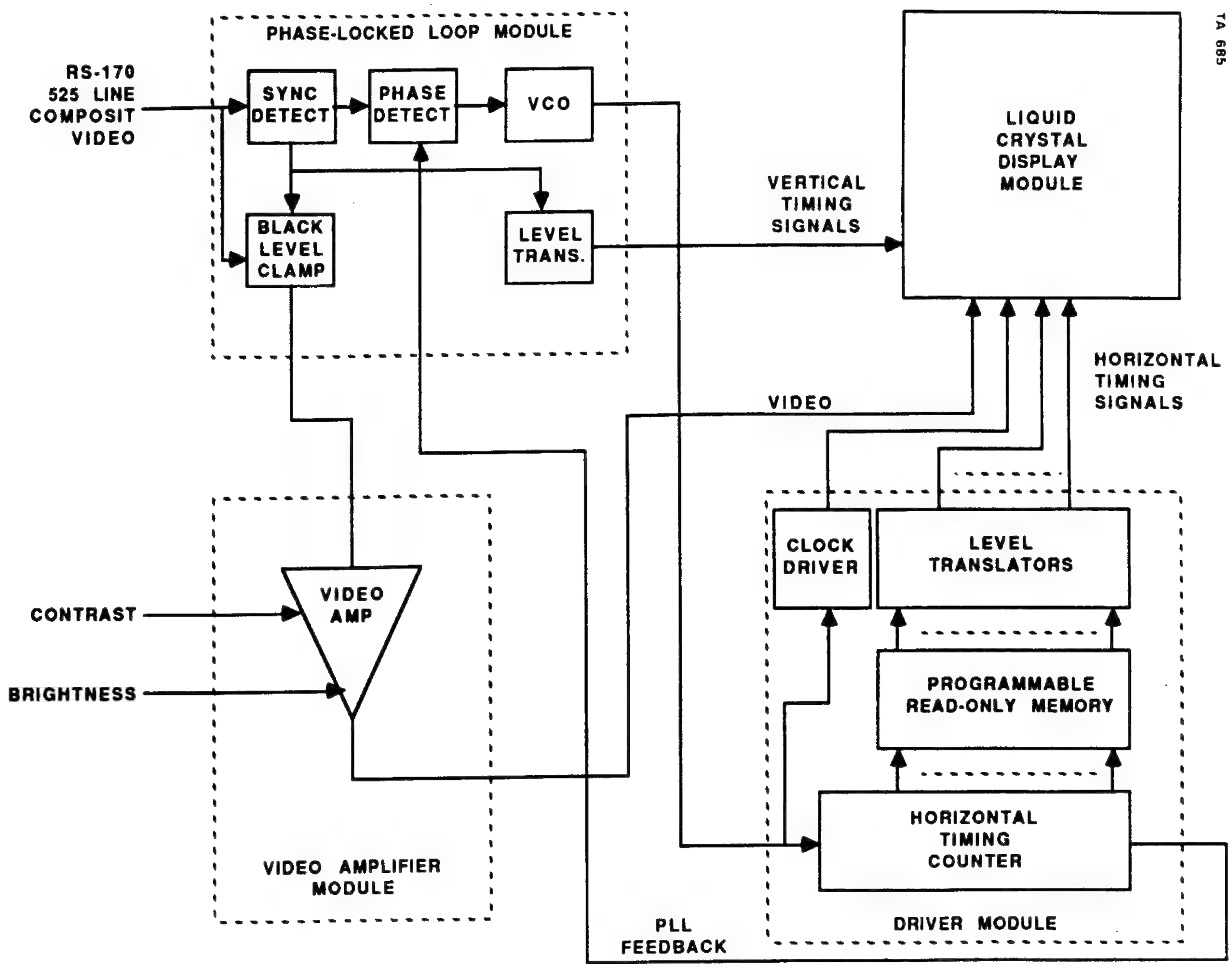

Figure 6. Block diagram of circuitry to interface liquid crystal device to composite video input.

The Phase-Lock-Loop Circuit Module also contains level translators for the vertical sync signals to the liquid crystal device.

The Video Amplifier circuit module receives DC-restored video from the Phase Lock Loop module and amplifies the 1-volt peak-to-peak input signal to the 25 volt peak-to-peak level required by the Liquid Crystal Device.

The Driver Module contains a horizontal timing counter that provides feedback for the phase locked loop. This counter is driven by the element clock and provides a feedback output every 392 clock pulses. The phase lock loop circuitry varies the element clock frequency such that the counter output is forced into synchronization with the input horizontal sync pulse. Thus the element clock frequency is exactly 392 times the horizontal line rate.

The horizontal timing counter also provides addresses for two programmable read-only memories that generate eleven different timing signals required by the liquid crystal module. In addition, this circuit module contains the circuitry required to translate the 5-volt logic levels into the 18 volt signals required by the liquid crystal module.

Projection Optics

As was illustrated previously in Figure 5, the projection lens must perform two separate functions. First, the lens must collimate the light from the optical fiber and then refocus the light reflected from the liquid crystal device onto the small aperture. Simultaneously, the lens must form an image of the desired size on the viewing screen. Thus the lens design must be optimized to meet requirements on the size of the spot formed at the aperture and the quality of the projected image.

As is shown in Figure 7, the projection optical system designed for the LXHMD is comprised of a 3-element projection lens and a single element field lens adjacent to the diffusing (viewing) screen. All of the lens elements are coated to improve optical efficiency and eliminate stray reflections, and are mounted in aluminum barrels. The barrels are mounted in plates that are supported by four cylindrical rods. The plates and lens mounts can be slide along the rods to adjust the lens-object, lens-aperture, aperture-screen distances to allow fine tuning of the projection system. Once adjusted, the lens mounts are locked in place with set screws. The characteristics of the optical system are summarized in Table 1.

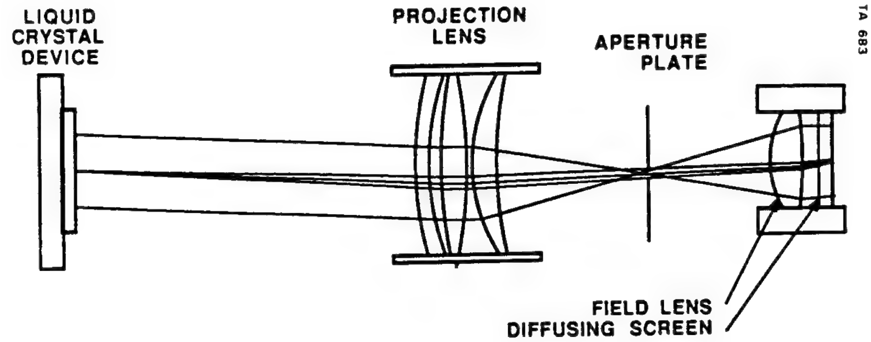

Figure 7. Projection optical system.

TABLE 1
OPTICAL SYSTEM CHARACTERISTICS

Object (LCD) Size, inches		0.75 x 1.0
Image Size, inches		0.47 x 0.63
Magnification Factor		0.63
Finite F-Number		17.4
Distortion		<2%
Modulation Transfer Function (MTF),	Center	>90%
	Corners	>85%
Over-all Length, inches		9.7

ILLUMINATION UNIT

The Illumination Unit is based on a Model 6137 Lamp House and accessories manufactured by Oriel Corporation. The light emitted by a Canrad Hanovia XBO-100 Mercury vapor arc lamp is collimated by a single element aspheric condensing lens. The collimated beam then passes through a filter holder in which an ultraviolet absorbing filter and one or more neutral density filters can be mounted. The filtered beam is focused by a 50 millimeter plano-convex lens onto the end of a fiber optic light pipe mounted in a custom holder.

The coupling of the light into the fiber optic bundle can be optimized by adjusting the position of the fiber and the lamp. The barrel around the end of the fiber is threaded; axial adjustment of the fiber position is obtained by screwing the fiber in or out of the holder. Once adjusted, the fiber position can be locked with a jam nut. Two knobs on the rear of the lamp house provide adjustment of the lamp position, which, in turn, varies the azimuth and elevation position of the focused spot.

ARC LAMP POWER SUPPLY

The arc lamp power supply is an Oriel Model 8510-1. This supply provides both the high voltage ignition pulse required to start the arc lamp and the low voltage, high current, DC power required once the lamp is ignited. The operating power level can be adjusted with a front panel control. The nominal operating power level of the lamp is 100 watts.

A switched 120-volt accessory outlet is provided on the rear panel of the power supply. The lamp house blower is normally connected to this outlet. In addition, the lamp house and power supply are equipped with a safety interlock feature. A switch inside the lamp house is connected to the power supply through a two-wire cable. This switch disables the power supply when the cover of the lamp house is removed.

3. ASSEMBLY AND OPERATION

The LXHMD hardware, as shipped, consists of the four previously described units, a fiber optic light pipe, and a set of filters. This section describes the set-up and operation of this hardware.

ELECTRICAL INTERCONNECTIONS

The following electrical interconnections must be made prior to operation of the LXHMD system:

Primary Power. The Arc Lamp Power Supply Unit and both Display Units must be connected to a standard 110-volt, 60 Hertz power outlet using the line cords attached to each unit.

Illuminator Unit Blower. The line cord from the blower on the Illuminator Unit should be plugged into the accessory outlet on the rear panel of the Arc Lamp Power Supply Unit.

Lamp Power Leads. The Illuminator Unit is equipped with two thick, white, high voltage leads that carry the power from the supply to the arc lamp. These leads should be connected to the two outputs on the rear panel of the Arc Lamp Power Supply Unit, taking care to observe the correct polarity. Polarity is marked on the tags attached to each lead and adjacent to the connectors on the power supply.

Lamp Safety Interlock. The two-wire cable from the lamp safety interlock switch must be plugged into the mating socket on the rear panel of the Arc Lamp Power Supply Unit. The power supply unit will not furnish a high voltage ignition pulse to the lamp unless this connector is engaged and the rear panel of the Illuminator Unit is in place.

Video Input. A standard RS-170 1-volt peak-to-peak video input must be applied to the BNC connector on the rear of each display unit. Both units have internal 75-ohm terminations.

ILLUMINATOR/FIBER OPTIC LIGHT PIPE ASSEMBLY

The threaded end of the fiber optic cable must be screwed into the fitting on the end of the Illuminator Unit optical system. The fiber should be rotated until the two jam nuts are flush against the end of this fitting. Care must be taken to avoid kinking or sharply bending the fiber during this operation.

The lamp house was properly adjusted prior to shipment, and, ideally, will not require adjustment after delivery. The following procedure can be used to optimize the light output of the illuminator unit if desired:

1. The fiber should be disconnected from one or both display units, and the light output from the loose end(s) of the fiber should be monitored with a calibrated photodiode detector.

2. The two large adjustment knobs on the rear panel of the Illuminator Unit should be adjusted alternately to maximize the light output from the fiber.

3. The jam nuts on the threaded portion of the fiber cable should be loosened and the fiber should be turned in or out of the fitting on the end of the Illuminator Unit optical system to maximize the light output. Care must be taken to avoid kinking or sharply bending the fiber.

4. Steps 2 and 3 should be repeated one or two times. The jam nuts on the threaded portion of the fiber should be tightened.

The two curved ends of the fiber optic cable must be engaged in the Display Unit optical systems as shown in Figure 8. The fiber must be inserted up

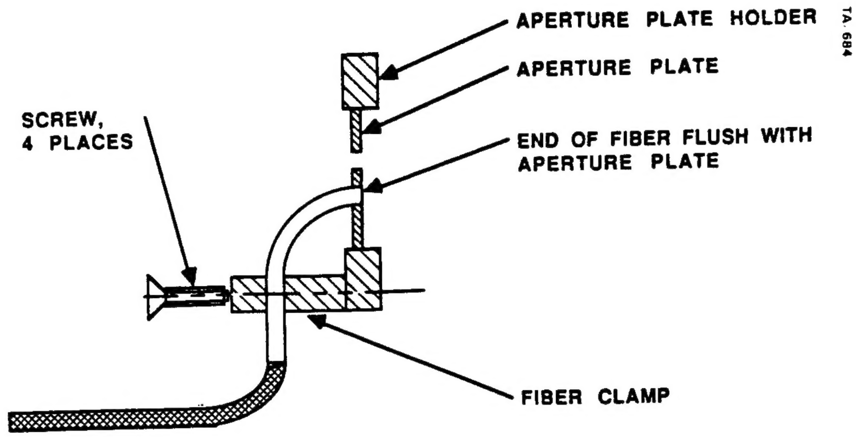

Figure 8. Proper installation of the optical fiber into the Display Unit projection optics.

through the fiber clamp on the bottom of the optical system. The end of the fiber must be fitted into the lower of the two holes in the aperture plate. Four screws on the fiber clamp must be loosened before the fiber is inserted and then tightened after the end of the fiber is properly engaged in the aperture plate.

A set of four filters are provided with the Illuminator Unit. The slightly yellowish filter labeled LP385 absorbs ultraviolet light. This filter must be placed in the filter holder at all times. The other three are neutral density filter that can be placed in the filter holder in any combination to reduce the net brightness of the displays.

CONTROLS

The operation of the Arc Lamp Power Supply is controlled as follows:

Power Supply On/Off. The primary power to the Arc Lamp Power Supply is controlled by a switch on the front panel. This switch also controls power to the accessory outlet on the rear panel of the supply. The blower on the Illuminator Unit is normally plugged into this outlet.

Lamp Start. The Start button on the front panel of the Arc Lamp Power Supply causes the supply to generate a high voltage pulse that initiates the arc within the lamp. A delay of about 30 seconds is required between the time power is applied to the Arc Lamp Supply and the actuation of the Start button.

Power Level Adjust. The Output level control can be used, in conjunction with the built-in meter, to set the proper power level for the lamp. The nominal lamp power level is 100 watts. Slightly higher power levels are acceptable. Operation at lower power levels may cause the lamp to extinguish.

Meter Function. A switch is provided to set the internal meter to measure either voltage applied to the lamp or current through the lamp. Both functions should be used to determine the lamp power level.

The Display Units are controlled as follows:

Power On/Off. The power on/off switch is located on the rear panel of each Display Unit.

Brightness. The brightness knob on the front panel of each Display Unit controls the average level of the video signal applied to the liquid crystal devices. As previously described, the absolute brightness of the image is controlled by filters placed in the Illuminator Unit.

Contrast. The contrast knob on the front panel of each Display Unit controls the peak-peak amplitude of the video signal applied to the liquid crystal device, and thus determines the contrast between the black and white states. Placing this control in the fully clockwise position produces maximum video amplitude and highest contrast.

4. CHARACTERISTICS AND PERFORMANCE

The characteristics and performance of the LXHMD hardware were measured in accordance with the Acceptance Test Procedure. The size, weight, and power consumption of the HVCPD Units are summarized in Table 2.

The optical performance parameters, brightness, contrast, and uniformity are summarized in Tables 3 and 4. While Display Unit S/N 001 easily achieved the contract goal of over 12,500 foot Lamberts, Unit S/N 002 fell short of this goal. In addition, the uniformity of S/N 002 was less than the goal. The low brightness and poor uniformity of S/N 002 are believed to be due to the fiber optic cable.

The major problem with both display units, and the problem that lead to the discontinuation of our development of reflective liquid crystal devices, is their low contrast ratios. While the design goal for contrast ratio was 24:1, the two Display Units achieved only between 3:1 and 8:1.

TABLE 2
PHYSICAL CHARACTERISTICS OF LXHMD HARDWARE

	Illuminator Unit	Arc Lamp Power Supply	Display Unit (2 Required)
Size, HxWxD			
Main Unit	9x5x5	5.5x10.5x13	7x8x11
Optics Extension	6x3DIA		8x2x2
Weight, Lbs	9	42	11
Power Consumption, Watts	(a)	350 (b)	30

(a) Illuminator Unit receives all power from the Arc Lamp Power Supply Unit.
(b) Includes power dissipated in Illuminator Unit.

TABLE 3
OPTICAL PERFORMANCE OF DISPLAY UNIT S/N 001

Brightness, fL	Left	Center	Right
Upper	46,800		41,500
Center		48,300	
Lower	39,200		46,900
Contrast Ratio	Left	Center	Right
Upper	8.0:1		(a)
Center		7.6:1	
Lower	6.4:1		(b)

(a) Contrast could not be accurately measured due to large number of point defects.

TABLE 3
OPTICAL PERFORMANCE OF DISPLAY UNIT S/N 002

Brightness, fL	Left	Center	Right
Upper	8,700		7,200
Center		12,200	
Lower	11,600		9,100
Contrast Ratio	Left	Center	Right
Upper	2.9:1		3.6:1
Center		3.3:1	
Lower	2.1:1		4.0:1